Higgs discovery at LHC

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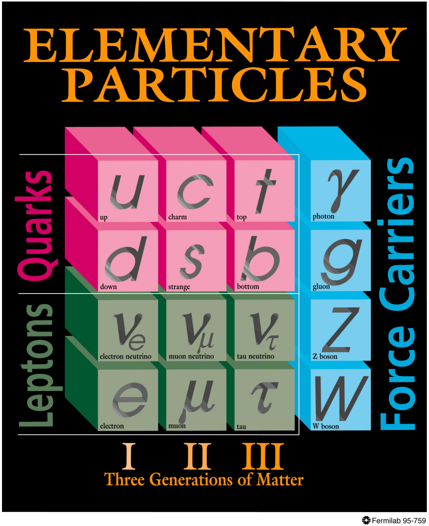
December 10, 2012

Introduction



- SM interactions can be explained by the group theory : $SU(3)_C \times SU(2)_L \times U(1)_Y$
- This symmetry does not allow massive bosons.
- Adding a field breaks spontaneously the symmetry allowing the bosons to have a mass.
- if we consider a field doublet (4 degrees of freedom), we can give a mass to the gauge bosons through the Higgs mechanism.

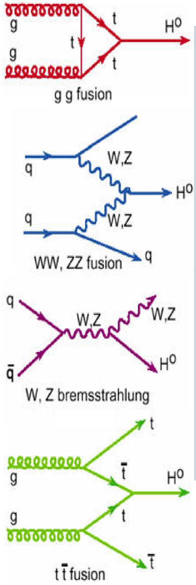
Introduction

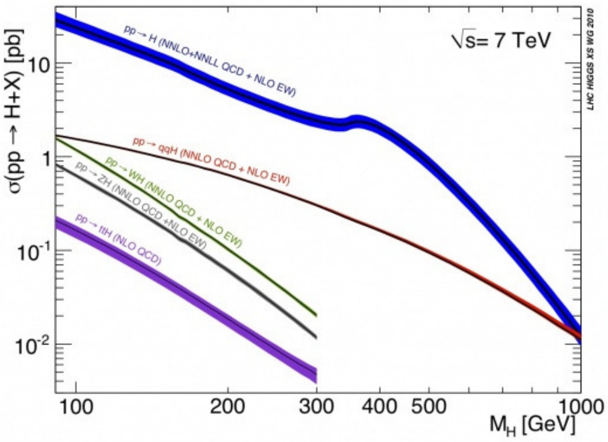
- 3 degrees of freedom are "eaten" to give the mass of the W^+, W^- and Z^0 bosons
- 1 degree of freedom remains (the photon is massless) giving a neutral scalar new boson : the Higgs boson
- The Higgs boson also explains the mass of the fermions through Yukawa couplings.
- The mass of the boson is not predicted by the SM but its couplings to the SM particles are proportionnal to the mass of the particle.

Introduction

- A new resonance has been discovered at the LHC $\sim$ 125 GeV.
- It looks like the SM Higgs boson but its properties and couplings to the SM particles have to be measured to confirmed the hypothesis.
- During the talk, I will show :
  - the ATLAS and CMS results
  - the caracterization of the new resonance properties
  - next steps to measure the Higgs couplings to the SM particles.

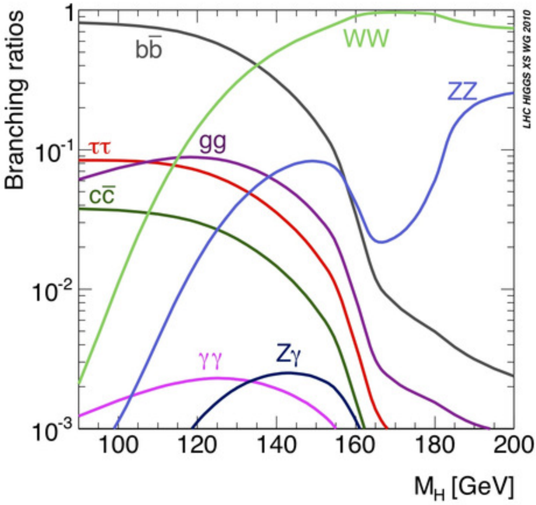
Higgs production





Cross-section of the Higgs boson production processes as a function of its mass.

Higgs decay

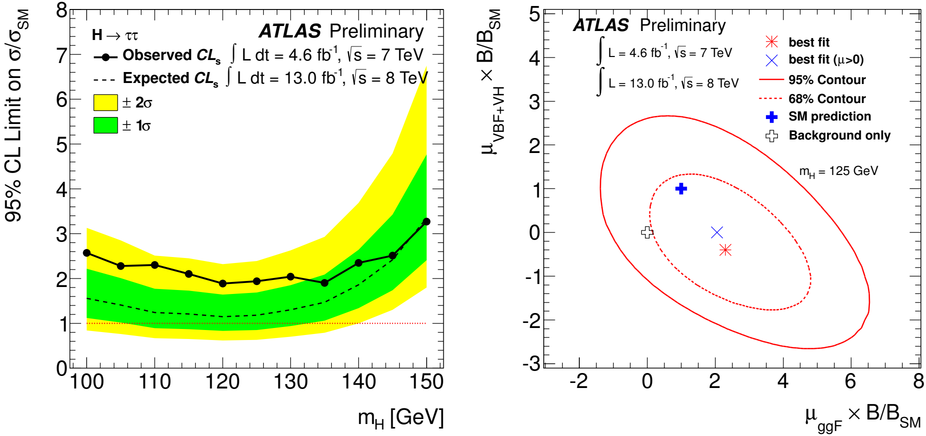


Branching ratio of the Higgs decay as a function of its mass.

$H \rightarrow \tau\tau$

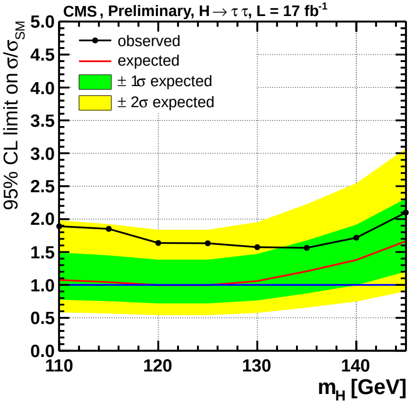
- This channel is sensitive to $m_H \sim$ 110-140 GeV
- Lepton and hadronic decay of the τ leptons are considered :
  - $H \rightarrow \tau^+\tau^- \rightarrow \ell\ell 4\nu$
  - $H \rightarrow \tau^+\tau^- \rightarrow \ell\tau_{had} 3\nu$
  - $H \rightarrow \tau^+\tau^- \rightarrow \tau_{had}\tau_{had} 2\nu$
- The main background is $Z \rightarrow \tau\tau$. Other background contributions :
  - Z+jets
  - Top production
  - Diboson
  - Fake leptons production (especially in the $\tau_{had}\tau_{had}$ channels).
- The events are split according to their jet-multiplicity (different analysis cuts)

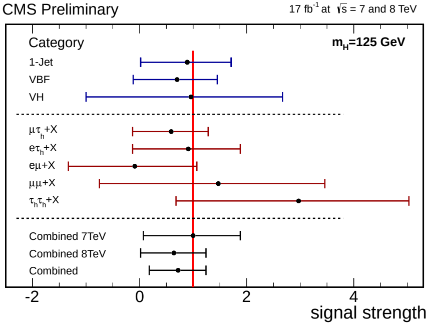
$H \to \tau\tau$ with ATLAS



C.L. limit on the production of $H \to \tau\tau$ (left) and best signal strengh fit (right).

$H \to \tau\tau$ with CMS



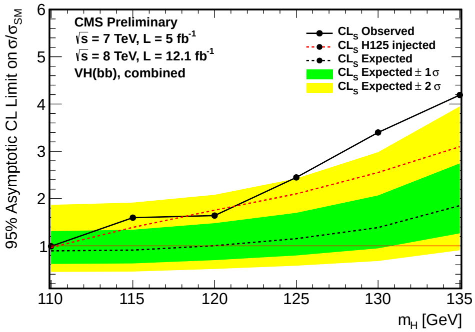


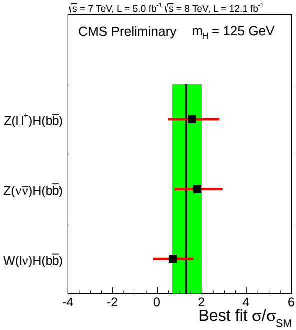
95% C.L. limit on the production of $H \to \tau\tau$ (left) and best signal strengh fit (right).

$Z/W\ H \to b\bar{b}$

- Channel benefits from large branching ratio
- Very large QCD background : associated production with lepton requirement to reduce the background
- WH 2 times larger XS than ZH, but WH has more background
- Event selection :
  - ZH$\to \ell\ell$: exactly 2 leptons, Z mass cut, remove high Etmiss, two leading jets b-tagged
  - ZH$\to \nu\nu$: large Etmiss, p_T^{miss} requirement, lepton veto, 2 jets b-tagged
  - WH : exactly 1 lepton, $M_T > 25$ GeV, Etmiss cut, exactly 2 jets b-tagged
- Backgrounds :
  - ZH$\to \ell\ell b\bar{b}$: Z+jets is the main backgrounds, then comes top and dibosons
  - ZH$\to \nu\nu b\bar{b}$: Z+jets and top, but W+jets and dibosons are a bit smaller
  - WH$\to \ell\nu b\bar{b}$: top, W+jets, multijet (QCD) are the main backgrounds, then come dibosons

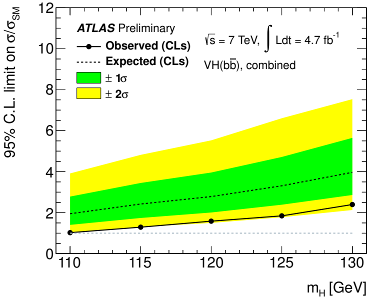
$Z/W\ H \to b\bar{b}$: CMS

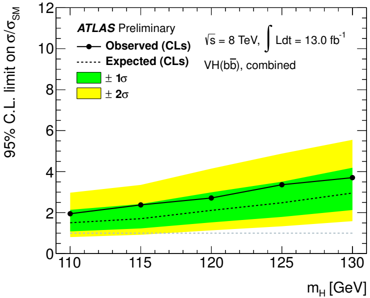


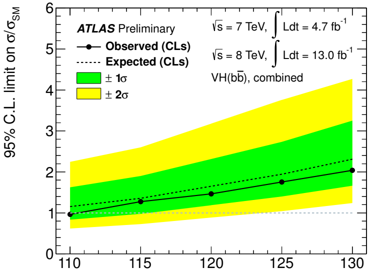


95% C.L. limit on the production of $H \to b\bar{b}$ (left) and best signal strengh fit (right).

$Z/W\ H \to b\bar{b}$: ATLAS



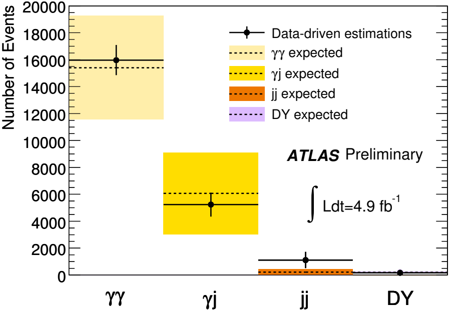




95% C.L. limit for 2011, 2012 and the combination.

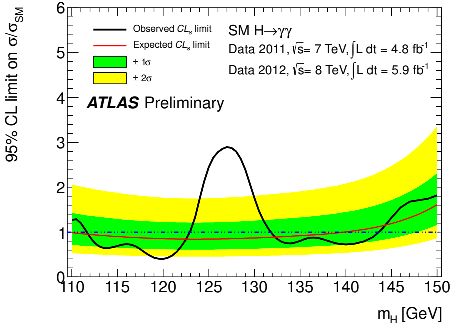
$H \to \gamma\gamma$ analysis

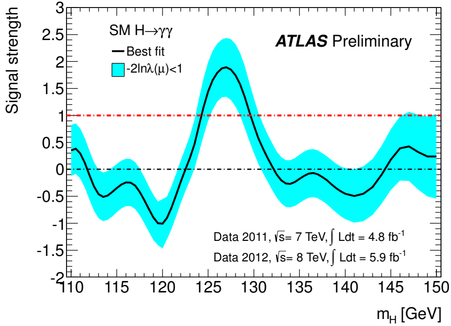
- $\gamma\gamma$ channel sensitive to $m_H \in [110 - 150]$ GeV
- benefits from good calorimeter resolution : 1.6 GeV for 120 GeV Signal
- 2 photons are required with $E_T^{\gamma_1} > 40$ GeV, $E_T^{\gamma_2} > 25$ GeV
- Main background : irreducible $\gamma\gamma$ (30 pb), reducible $\gamma - jet$ (200 nb) and $jet - jet$ (500 μb)
- Powerful $\gamma - jet$ separation used based on calorimeter shower-shape and isolation cuts



- Background composition from control samples by reversing isolation or identification criteria : Fraction of ir reducible $\gamma\gamma$: $(71\pm5)\%$

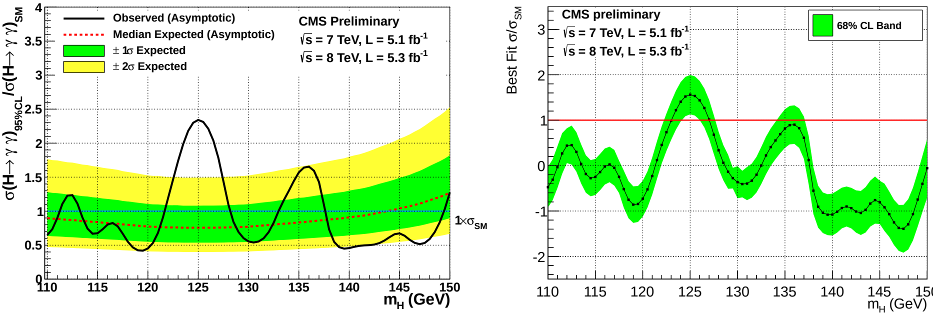
$H \rightarrow \gamma\gamma$ with ATLAS





95% C.L. limit on the production of $H \rightarrow \gamma\gamma$ (left) and best signal strengh fit (right).

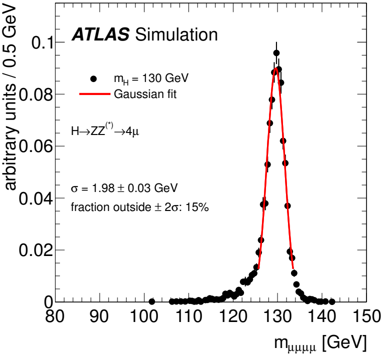
$H \to \gamma\gamma$ with CMS



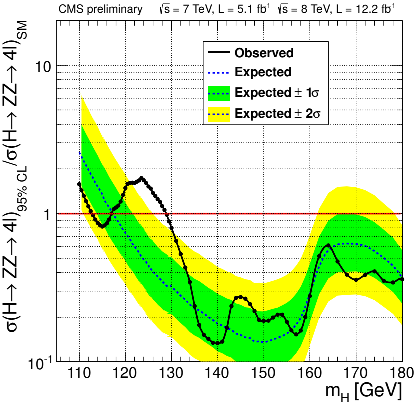
95% C.L. limit on the production of $H \to \gamma\gamma$ (left) and best signal strengh fit (right).

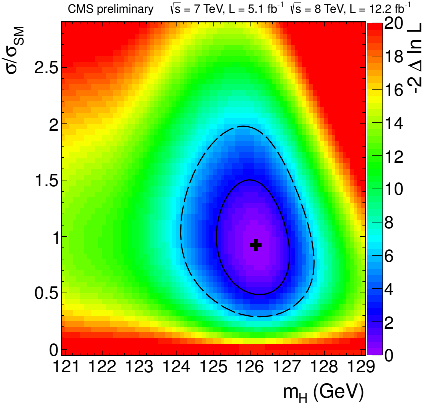
$H \rightarrow ZZ^* \rightarrow \ell\ell\ell\ell$

- Low branching ratio in the low mass region
- Sensitivity in low and high Higgs mass
- Benefits from good mass resolution (130 GeV: 1.5-2%)
- Backgrounds :
  - ZZ^* from simulation
  - $Z + jets$: control region without charge, isolation and impact parameter criteria on the second lepton pair.
  - $t\bar{t}$: $e^{\pm}\mu^{\mp}$ pair consistent with m_Z and two additional same-flavor leptons.



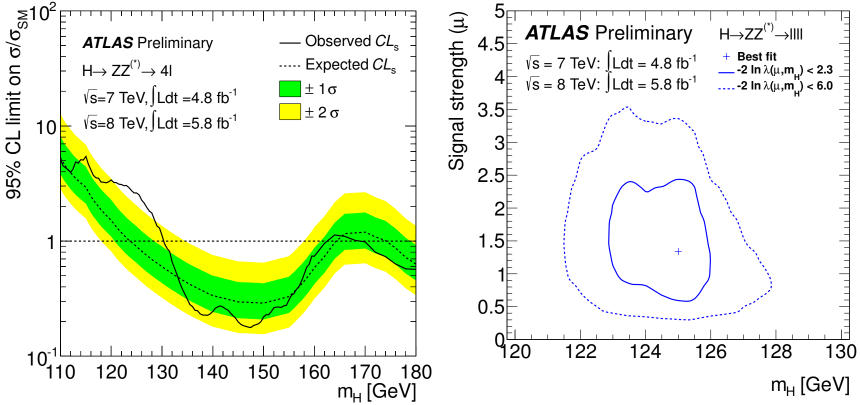
$H \to ZZ^*$ with CMS





95% C.L. limit on the production of $H \to ZZ^*$ (left) and best signal strengh fit (right).

$H \to ZZ^*$ with ATLAS

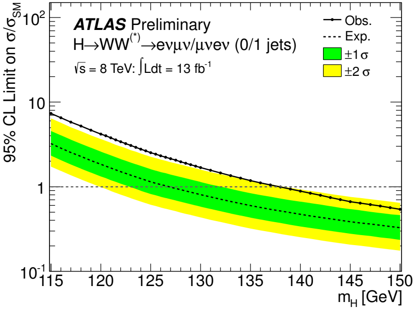


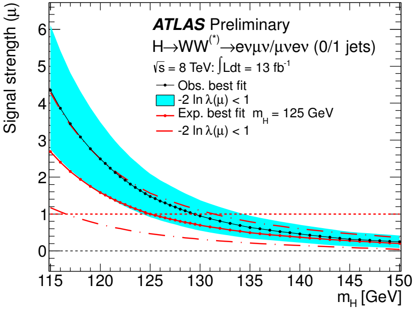
95% C.L. limit on the production of $H \to ZZ^*$ (left) and best signal strengh fit (right).

$H \to WW^* \to \ell\nu\ell\nu$

- This channel is sensitive to $m_H \sim$ 120-180 GeV
- No mass reconstruction due to the neutrinos : use $m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\vec{p}_T^{\ell\ell} + \vec{p}_T^{miss}|^2}$ with E_T^{miss} the missing transverse momemtum.
- Selection :
  - 2 isolated oppositely charged lepton ($p_T > 25$, 15 GeV)
    Reduce W+jets and QCD background
  - Large missing energy and Z veto in case of same-flavor lepton pair
    Reduce Z background
  - $E_T^{miss\ \ rel} = E_T^{miss} * sin(\Delta\phi(\vec{p}_T^{\ell}, \vec{E}_T^{miss}))$, with closest lepton in ϕ
    Reduce fake missing energy
  - b-jet veto
    Reduce top background
  - $m_{\ell\ell}$ and $\Delta\phi_{\ell\ell}$ cuts
    Reduce SM WW background, $H \to WW$ produces polarized W bosons
  - Jet multiplicity dependent cut : $p_T^{\ell\ell}$, $\vec{p}_T^{tot}$
    Reduce Drell-Yan and soft QCD backgrounds

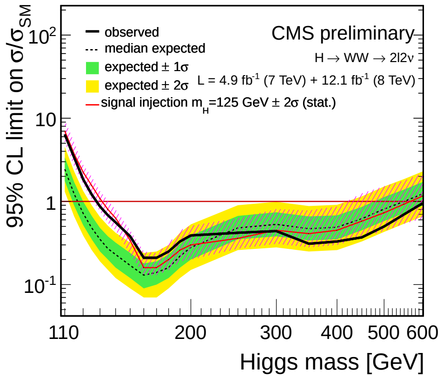
$H \to WW^*$ with ATLAS

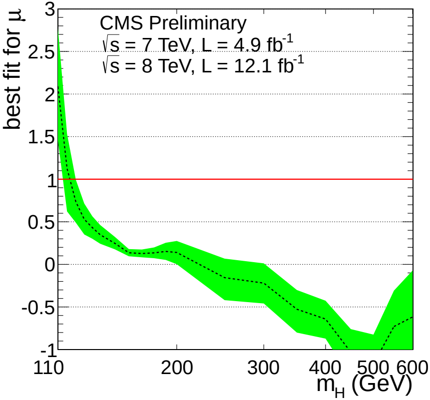




95% C.L. limit on the production of $H \to WW^*$ (left) and best signal strengh fit (right).

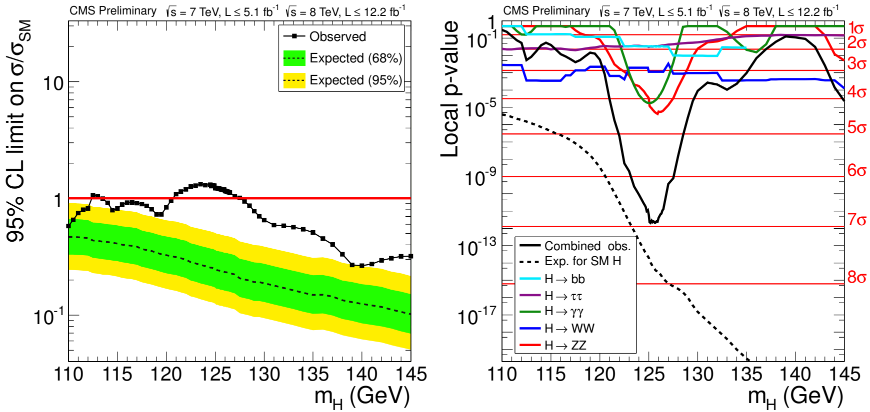
$H \to WW^*$ with CMS





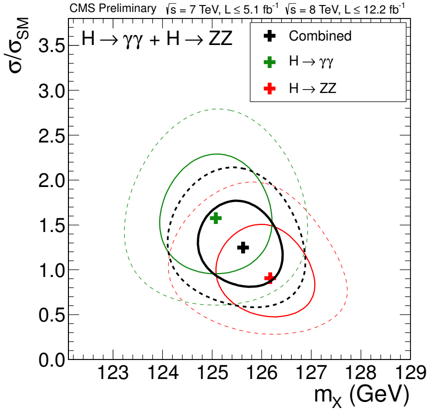
95% C.L. limit on the production of $H \to WW^*$ (left) and best signal strengh fit (right).

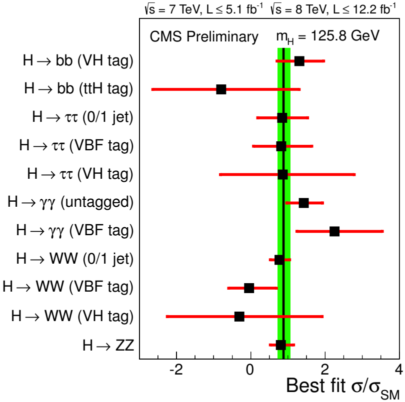
Combination of the channels with CMS



95% C.L. limit on the combinations of the CMS channels (left) and local p_0 value for the combination (right).

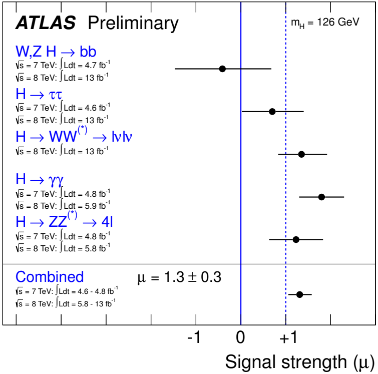
Combination of the channels with CMS

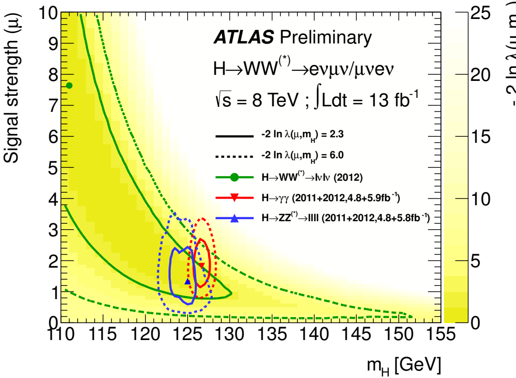




Best fit signal strengh of the CMS channels.

Combination of the channels with ATLAS





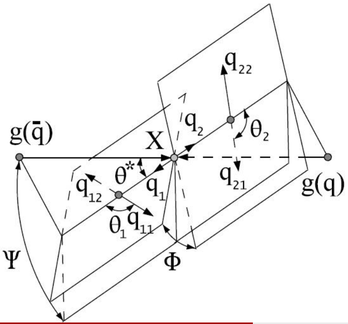
Best fit signal strengh by combining the Atlas channels.

Boson properties

- The production rate of the new boson seems compatible with the SM predictions (within the uncertainty).
- The decay branching fractions are consistent with the SM but experimental measurements do not allow for an unambiguous conclusion.
- The width of the new particle is consistent with being smaller than the experimental resolution ($\sim$ GeV)
- The new boson cannot have a spin one because it decays to two on-shell photons (Landau-Yang theorem)
- The new boson intereacts with massive gauge bosons, so we expect that it plays a role in the electroweak symmetry breaking.

Measurement of the Spin and Parity

- The spin and parity of the new boson will impact the kinematic distributions of its decay particles.
- $H \rightarrow ZZ^* \rightarrow 4\ell$ channel allows a complete measurement of the Z bosons polarization.
- $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^* \rightarrow 2\ell 2\nu$ channels have less kinematic informations available but can complement de resonance properties measurements.



$m_{V_1 V_2}$, m_{V_1}, m_{V_2} and six angles fully characterize the kinematic of the process.

Measurement of the Spin and Parity

Plots taken from arXiv:1208.4018v1 [hep-ph]

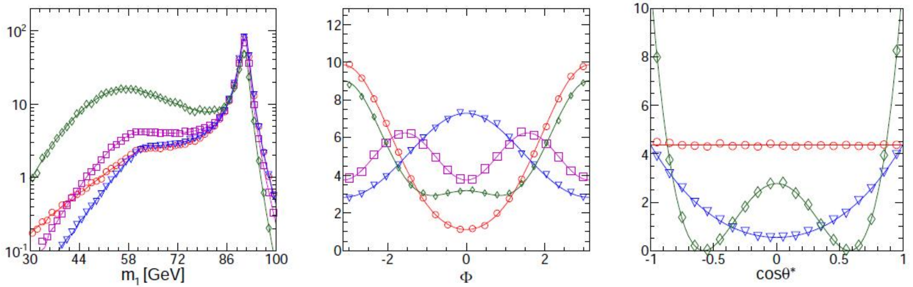


FIG. 2: Distributions of some of the representative observables: m_1 in the $X \to ZZ$ analysis (left), Φ in the $X \to WW$ analysis (middle), and $\cos\theta^*$ in the $X \to \gamma\gamma$ analysis. Four signal hypotheses are shown: SM Higgs boson (red circles), 0^- (magenta squares), 2^+_m (blue triangles), 2^+_h (green diamonds), as defined in Table I. Points show simulated events and lines show projections of analytical distributions. Here and throughout the paper, where only shapes of the distributions are illustrated and unless otherwise noted, units on the y axis are arbitrary.

Method to extract the spin and parity

- Possible method : matrix element to distinguish different spin-parity hypotheses.
- Measurements (angular and mass distributions) become a fit parameter
- Multiparameter fits require a large amount of data
- For a medium term analysis, we can simplify the method by using just two observables. We can also assume that the observed resonance is a mixed spin-parity state and fit for ratios.

Expected sensitivity to measure the spin and parity

Plots taken from arXiv:1208.4018v1 [hep-ph]

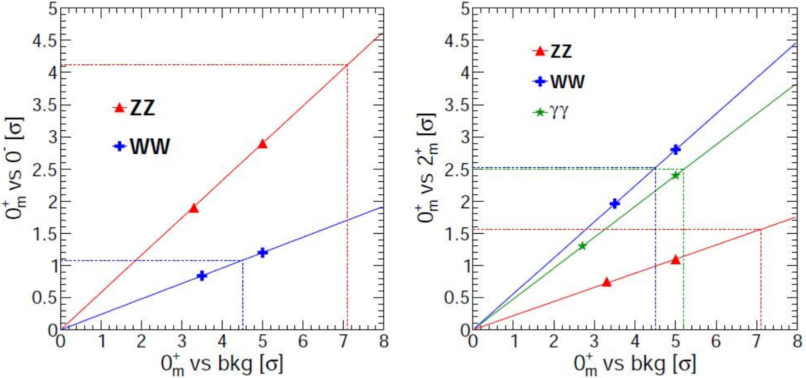


FIG. 10: Expected hypotheses separation significance versus signal observation significance for the SM Higgs boson versus 0^- (left) and 2^+_m (right) hypotheses. Points show two luminosity scenarios tested with generated experiments and expectations are extrapolated linearly to other significance scenarios. Dashed lines indicate what might be expected with 35 fb^{-1} of data at one LHC experiment.

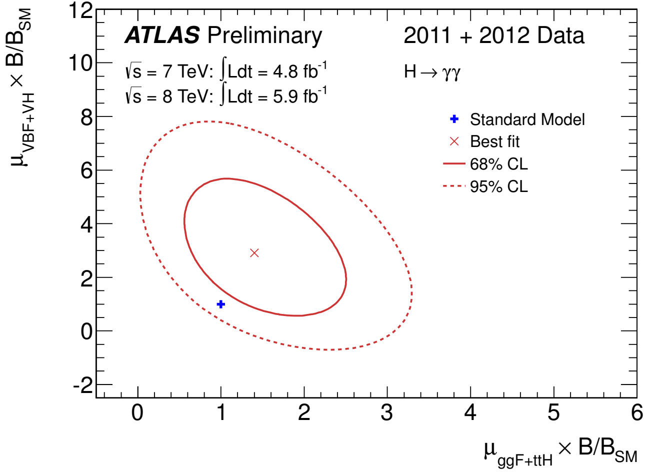
Measuring the Higgs couplings to other particles

- Several channel have been studied providing sensitivity to the coupling properties of the new resonance.
- To extract individual coupling, we perform a combined fit using all the production and decay channels sensitive to the new boson.
- For each channel, the number of observed events is proportional to the coupling to the particles involved in the production mechanism and to the coupling to the particles involved in the decay mode.
- Systematic uncertainties and their correlations have been included in the combined fit.
- One channel can have different contributions from various production modes.
- Combining multiple decay modes is complicated by the fact that the couplings between the Higgs boson to the other particles affect both the production and the decay.
- The presence of new particle states in loop-induced couplings and unobserved decay modes affect the total width of the Higgs boson.

Measuring the Higgs couplings to other particles

- No $t\bar{t}H$ production has been observed yet, so μ_{ggH} and $\mu_{t\bar{t}H}$ are grouped together since they scale dominantly with the $t\bar{t}H$ coupling in the SM
- Similarly, μ_{VBF} and μ_{VH} have been grouped together since they scale to the WH/ZH couplings within the SM.
- In the fit, we assume :
  - Only the absolute values of couplings are taken into account : the observed boson is assumed to be a CP even scalar as in the SM
  - The signals observed in different search channels originate from a single narrow resonance with a mass of 126 GeV (for ATLAS)
  - The width of the Higgs boson is assumed to be neglegible.

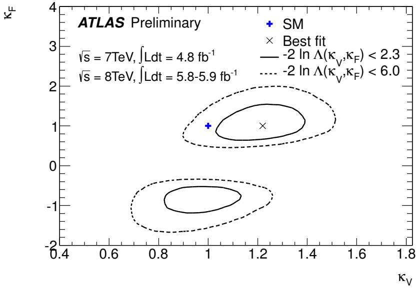
Measuring the Higgs couplings to other particles



Measuring the Higgs couplings to other particles

- To extract the couplings to fermions and vector gauge bosons, we need an extension of the single parameter μ fit.
- Assuming the total width of the Higgs boson is given by known SM particles, the fit parameters are the coupling scale factors :

$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$$
$$\kappa_V = \kappa_Z = \kappa_W$$



Plot from ATLAS-CONF-2012-127

Conclusions

- 2012 is a very exciting year : a new boson $\sim$ 125-126 GeV has been discovered.
- The new resonance looks like the SM higgs boson but it is too soon to conclude.
- After decades of searches, we start to have a clue on the EW symmetry breaking predicted by the group theory.
- Beyond Standard Models are not excluded, the properties measurements of the new resonance will tell us if it is the SM Higgs boson or a boson explained by a more complex theory.
- Many years of work to understand the physics of the new boson (new students are welcome in the ATLAS collaboration)

Thanks

I would like to thank the organizers to have invited me.